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AN R&D PROGRAM ON PROTECTIVE COATINGS USED IN FGD SYSTEMS

Report No. 87-245-K

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ABSTRACT

This report outlines a two year R&D program on protective coatings used in FGD systems. The overall objective of the proposed program is to establish an in-house testing, evaluation, problem solving and research capability for FGD systems materials at Ontario Hydro. It is planned to execute the program in two twelve-month phases. It is anticipated that the results of the program will enable Ontario Hydro to address the potential FGD materials failure problems in a reliable and well informed manner.

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32-500-850	837.03222	December 14, 1987	87-245-K

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EXECUTIVE SUMMARY

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As a result of acid rain pollution problems, regulations have been imposed on industries to reduce acid gas emissions. In compliance with the provincial regulation, one of the options Ontario Hydro is considering is the installation of FGD Scrubbers to control SO_2 emissions. As part of this overall plan, Design and Development - Generation Division is coordinating an FGD program whose current objective is to recommend the preferred process for Hydro's first FGD application, assumed to be at Lambton GS.

One of the most serious problems associated with FGD systems-poor reliability-has been the failure of construction materials. Abrasion, erosion and corrosion are some of the major causes that contribute to FGD materials failure. Since the advent of SO_2 removal systems, materials of construction have progressed remarkably in terms of their resistance to FGD environments, and although expensive metal alloys and organic linings have been used, their overall performance is still unsatisfactory. The persistent problem with materials failure is partly due to the severe conditions that exist in the scrubber systems, lack of reliable materials performance data, and in some cases, unavailability of the best materials.

In view of Ontario Hydro's plan to install scrubber systems for controlling SO_2 emission, it is essential to establish an in-house FGD materials testing and evaluation program to address potential materials failure problems. The Materials Chemistry Section of the Chemical Research Department has prepared this document proposing such a program. The overall objective of the program is to establish an effective in-house testing, evaluation, problem solving and research capability for FGD systems materials at Ontario Hydro.

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To: Dr. D. Mills
Director of Research

AN R&D PROGRAM ON PROTECTIVE COATINGS USED IN FGD SYSTEMS

G. Gowda

1. INTRODUCTION

Ontario Hydro is considering the installation of FGD scrubbers as one of several options to ensure that our future acid gas emissions meet the levels established by the provincial government. Within Ontario Hydro, this FGD Program is being coordinated at the present time by Design and Development - Generation Division. To meet Ontario Regulation 662/85, efforts are underway to study the option of installing 2-500 MW high efficiency scrubbers by 1994, 4 by 1996 and a total of 12 by the year 2001. Initial efforts are directed towards installing two scrubber units at Lambton GS. Within the overall FGD Program, Operations Engineering and Project Management Department is coordinating the "A" level responsibility, and "B" level activities are being coordinated by Environmental Studies and Assessments Department. The "B" level activities include the Lambton FGD Process Selection Studies and Assessment of Environmental Impacts. Among the many responsibilities within the FGD Process Selection Studies Sub-program, the selection and recommendation of FGD construction materials is carried out by Mechanical Design Department of D&D-Gen, and process chemistry selection and recommendation is assigned to the Process Chemistry Section of the Chemical Research Department. Recently, Design and Development Division issued a report entitled "Materials Considerations for Wet Flue Gas Desulfurization Process Equipment," No. 87-278, recommending specific materials for the limestone, dual alkali and limestone slurry processes.

Since the advent of SO_2 removal systems, materials of construction have progressed remarkably in terms of their performance. However, some of the major problems which have

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plagued the operation of these systems to date are still related to materials failure. The persistent problems with materials failure is due to the severe conditions that exist in the scrubber systems, lack of reliable materials performance data which could help to select proper materials, and in some cases, unavailability of the most suitable materials.

Materials Chemistry Section is proposing an R&D program to address potential FGD materials failure issues, including their reliability, performance, novel materials identification, and test and evaluation methods.

2. OBJECTIVES

Phase I: To develop test methods and generate reference performance data for FGD materials currently in use, such as metal alloys, organic linings and coatings, and inorganic linings.

Phase II: To identify and evaluate new ceramic and organic materials for potential applications in FGD systems of interest to Ontario Hydro.

3. BACKGROUND INFORMATION

An FGD system is a complex piece of equipment, having distinct components and experiencing a range of operating conditions. Given the extremely varied service conditions, a single material cannot be used in the construction of an FGD system. There are several processes and designs available, and the technology in this field continues to advance with the ultimate aim of providing for reliable and cost effective removal of sulfur dioxide. Depending on the type, design and process, some system components and materials of construction vary from one system to another. However, in the majority of cases, the major components, operating conditions and materials of construction are similar.

One of the most serious and common problems associated with the operation of FGD systems has been the failure of construction materials by abrasion and corrosion. Furthermore, materials failure in FGD systems is considered to be the dominant cause of poor reliability. Although expensive alloys, organic and inorganic protective linings have been used to alleviate this problem, their overall performance is still unsatisfactory. The degree of failure/performance in FGD systems is a function of the materials themselves and their environment. Materials selection for a particular zone in an FGD system is based on the conditions that exist in that zone. The service environments experienced by FGD materials are very complex and aggressive, and they are

classified into the following categories: chemical, erosion/abrasion, and temperature; with the severity of these categories varying from component to component.

The chemical conditions that can exist within an FGD system vary widely. During normal operations, the pH of the liquors in various sections of the scrubber circuit are usually predictable and fairly stable. However, upset operations can cause the pH conditions to change from very acidic to fairly alkaline, resulting in a major change of the corrosivity in a particular location. Another chemical factor is the presence of chlorides and fluorides which enter the scrubbing circuit from either water or the coal. Chloride concentrations in scrubber loops can reach very high levels, depending upon the particular design. Fluorides and chlorides can cause severe corrosion of various metals and alloys. Fluorides can react with siliceous materials and may, depending on their concentration, attack some fillers and reinforcements used in linings. Some areas of the FGD system are also subject to severe abrasion because of the velocities of flue gas slurries used for scrubbing. The overall temperatures are not very high, however, they do vary over a wide range. Under normal operating conditions, the temperatures can vary from 160°C at the flue gas entrance to 50°C at the scrubber outlet. The components with the most aggressive service conditions are scrubber inlets (wet/dry zone interface), outlet ducts, stacks, outlet dampers, reheaters and wet fans.

A variety of construction materials have been used to date, including unlined carbon steel, carbon steel protected with polymeric coatings or rubber, alloys, and inorganic linings. The performance characteristics of each material depends on the zone and the environment in which it is used. The principal requirement for materials used in FGD systems is resistance to the prevailing severe process conditions. They should be capable of withstanding abrasion, corrosion, erosion, thermal shock, and general wear and tear.

Unlined carbon steel has been satisfactorily used in components where alkaline conditions are maintained. In the components where sulfurous and sulfuric acids are present, corrosion resistant alloys are used. The alloys have been known to undergo different types of attacks in the various components of the FGD system. Depending on the existing conditions in a component, they are known to fail due to pitting, crevice corrosion, stress-corrosion cracking, or erosion. A large amount of Type 316L stainless steel has been used in FGD system components such as prescrubbers, absorbers, spray nozzles, reheaters and dampers. Inconel 625 and Hastelloy G has been used to a limited extent in critical locations such as outlet ducts, outlet dampers and reheaters. In general, alloys do not perform well under conditions where chlorides are present.

Organic linings have been used extensively in various components of FGD systems. The high cost of corrosion-resistant alloys is one of the main reasons for increased use of plastics and organic lined carbon steel in the scrubber systems. Natural and neoprene rubber is one of the forms of organic lining used in addition to several resins such as, polyester, vinyl ester, epoxy and fluoropolymers. To be effective, the organic coatings are applied much more thickly than typical coatings to a carefully cleaned metal surface. Failure of organic linings occur by blistering, debonding, wear from abrasive slurries, and temperature variations. Organic lining materials used to date in scrubbers are known to provide corrosion protection when covered with more erosion resistant materials such as prefired bricks. Poor performance has been related to improper selection of linings for the equipment design, inadequate surface preparation and improper application.

The major use of inorganic materials in FGD systems has been for protective linings in abrasive or hot acidic environments. The types of inorganic materials used are prefired bricks, concretes and mortars. These have the advantages of better high temperature and erosion resistance than the organic coatings but they are generally permeable and thus do not totally protect the substrate from corrosive environments. To decrease the permeability, some inorganic protective coating systems utilize an organic coating between the metal surface and the ceramic. However, this multi-barrier approach reduces the cost benefit of the system over the corrosion resistant alloys. Ceramic linings are commonly used in gas entry ducts, scrubber entry chambers, venturi throats, bases of venturi scrubber receivers, outlet ducts, stacks, spray nozzles and slurry pumps.

Acid-resistant bricks are used in stack linings, and are made of fireclay. Alumina bricks are more abrasion resistant than acid-resistant bricks and will also withstand hot sulfuric acid conditions so that they have been used to line venturi throats. Silicon carbide shapes have high abrasion and chemical resistance and are used for spray nozzles and pump components, as well as for lining venturi throats. Prefired bricks and shapes are known to resist FGD system service conditions except for hydrofluoric acid which could attack silicate bonds. Ceramic linings are commonly applied by gunite technique, by casting and by troweling.

As part of the overall proposed programme objective, some high performance ceramic materials will be evaluated for potential applications in FGD systems. Therefore a brief background information on these materials including their applications and properties is given below.

Advanced ceramics may be defined as nonmetallic, multicomponent inorganic solids, often multi-phased, and with complex crystal

structures. They are typically prepared by the sintering of fine, pure, and composition controlled powders. Compared with metals, ceramics have superior wear resistance, high-temperature strength, and chemical stability; they also generally have lower electrical and thermal conductivity. The principal disadvantage of ceramics as structural materials is the sensitivity of their strength to extremely small flaws, such as cracks, voids, and inclusions.

Ceramics have been widely used as monolithic bulk components and as thin coatings on a substrate in structural and electrical industries. The coating approach offers several advantages. One is the ability to optimize independently the properties of the surface region and those of the base material for a given application. A second advantage is the ability to maintain close dimensional tolerances of the coated work piece, since very thin coatings are often sufficient for a given application. Further, cost savings are obtained by using expensive, exotic materials only for thin coatings and not for bulk components. Finally, it is often cheaper to recoat a worn part than to replace it.

A number of ceramic coating compositions have been developed to protect or lubricate a variety of substrate materials, including metals, ceramics, and cermets. Many different processes are in use for the fabrication of ceramic coatings and for the modification of surfaces of ceramic coatings and of monolithic ceramics. Applications of ceramic coatings include ultrahard coatings for cutting tools, thermal insulation and lubricating coatings for adiabatic diesel engines and cooled gas turbines, and heat exchangers in the utility industry.

4.0 PROPOSED PROGRAM

The overall objective of the program is to establish an in-house R&D program to test, evaluate and characterize FGD construction materials at Ontario Hydro, and to evaluate new materials for potential FGD applications. In order to achieve the objectives several major tasks identified in the program have to be completed. The inter-relationships between the major tasks of the proposed program are schematically illustrated in Figure 1. Details of these tasks are described below.

4.1 Phase I: Development of Test Methods, and Reference Performance Data Generation for FGD Materials Currently in Use

4.1.1 Review and Selection of Currently Used Construction Materials and Service Environments

Using the Design and Development Division Report No. 87-278 as a reference, the three generic FGD systems under consideration at

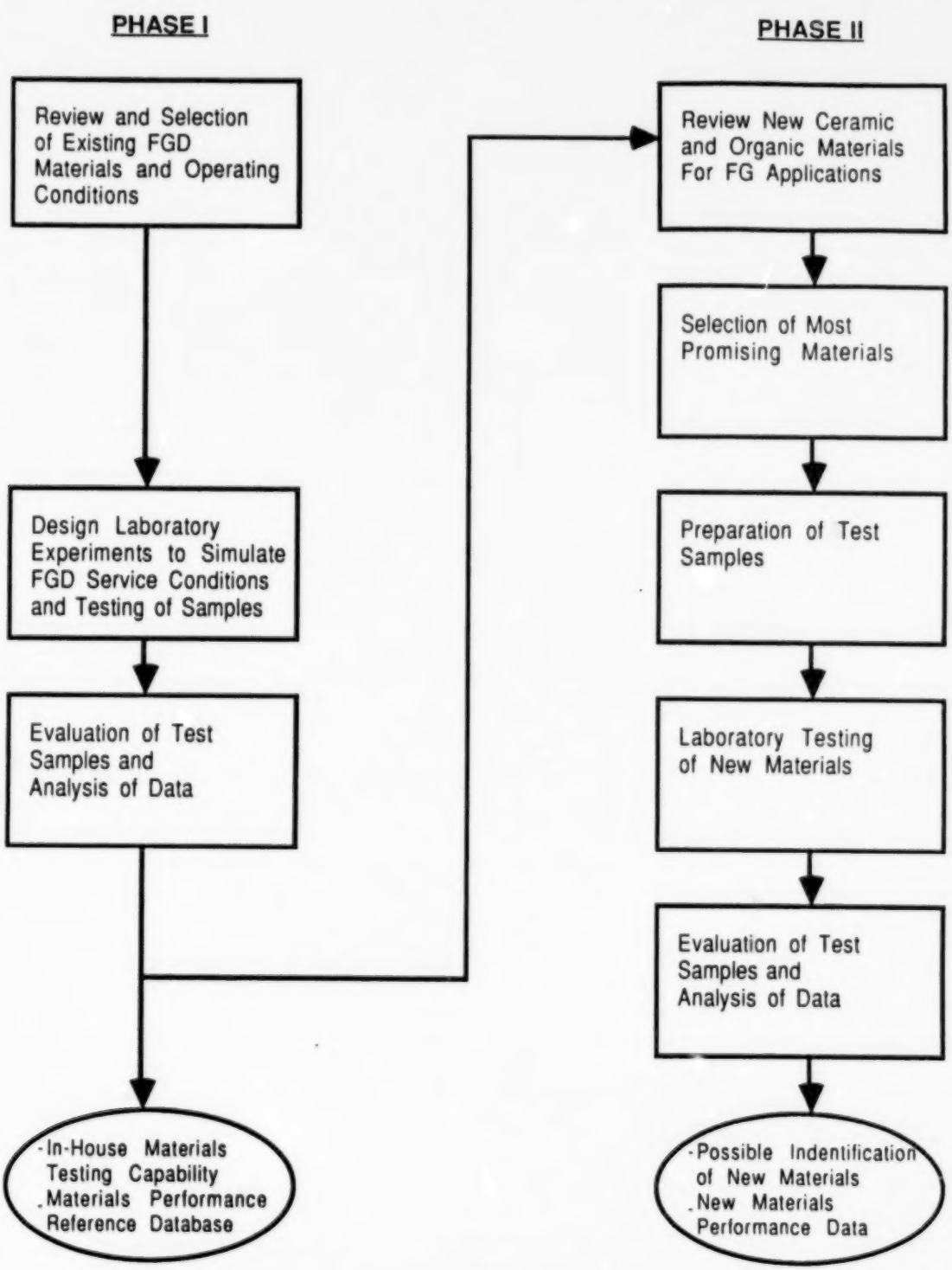
PHASE I
Review and Selection of Existing FGD Materials and Operating Conditions
Design Laboratory Experiments to Simulate FGD Service Conditions and Testing of Samples
Evaluation of Test Samples and Analysis of Data
-In-House Materials Testing Capability
.Materials Performance Reference Database
PHASE II
Review New Ceramic and Organic Materials For FG Applications
Selection of Most Promising Materials
Preparation of Test Samples
Laboratory Testing of New Materials
Evaluation of Test Samples and Analysis of Data
-Possible Indentification of New Materials
.New Materials Performance Data

FIGURE 1
FLOW-CHART SHOWING THE INTERRELATIONSHIP BETWEEN THE MAJOR TASKS OF THE PROGRAM

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Ontario Hydro will be reviewed further. The purpose of this task is two fold:

(1) to identify prevailing service environments, commonly used construction materials, materials performance characteristics, causes of materials failure, and reliability history;

(2) selection of materials and service environments for laboratory testing. Materials such as plastics, inorganic linings, metals and alloys will be considered.

4.1.2 Design Laboratory Experiments to Closely Simulate Scrubber Environments and Testing of Selected Materials

Experiments will be designed on a laboratory scale to closely simulate chemical, erosion/abrasion, and temperature environments that exist in the FGD systems considered by Ontario Hydro. The specific chemical formulations and other conditions required to simulate actual service environments will be chosen in consultation with utility companies and other laboratories who have had experience in this area, and by assessing the available literature information. Selected materials will be tested for corrosion resistance, abrasion resistance, thermal tolerance and erosion resistance.

4.1.3 Evaluation of Test Samples and Analysis of Data

The samples tested under a specific environment will be evaluated for their performance using the standard techniques (for example ASTM methods). For instance, to measure the corrosion resistance performance of an organic lining on a metal substrate, the samples will be evaluated for coating conductance, tensile adhesion, weight gain, cathodic delamination and blistering etc.. The details of other parameters and required evaluation techniques will be identified and developed during the course of the program. The overall results of the performance characteristics of the materials will be correlated and analyzed with respect to variables such as, coating application, the preparation of the metal surface in the case of linings, materials from different sources, and available field test results.

The materials performance data base thus established in Phase I will be used as a reference standard for evaluating the performance of new ceramic materials in Phase II.

4.2 Phase II: Evaluation of New Non-Metallic Materials for Potential Applications in FGD Systems

4.2.1 Review of Novel Commercially Available Ceramic and Organic Materials Suitable for FGD Systems

A review and evaluation of commercially available new non-metallic materials with potential for application in FGD systems will be carried out. Published literature data will be used to perform this task, and particular emphasis will be placed on organic and ceramic materials.

4.2.2 Selection of Most Promising Materials for FGD Environments

From the review conducted in task 4.2.1, materials with most promise will be selected for further study. Selection of materials will be based on the properties of the materials and their expected performance under the scrubber environments developed in Phase I.

4.2.3 Preparation of Test Samples

Selected materials will be prepared as thin coatings or as linings on metal substrates for laboratory testing. Where possible, commercially available samples will be utilized.

Various techniques of sample preparation will be investigated. For example, plasma spray for ceramics and spraying or casting for organic polymers.

4.2.4 Laboratory Testing of Samples

The samples prepared in task 4.2.3 will be tested for corrosion resistance, abrasion resistance, thermal tolerance and erosion resistance under identical service environments and experimental conditions designed in Phase I.

4.2.5 Evaluation of Test Samples and Analysis of Data

As in Phase I, the samples tested under a specific service environment will be evaluated for their performance using standard techniques as described in 4.1.3. The necessary parameters and evaluation techniques to assess the performance of these materials will be further developed during the course of the program. The results will be correlated with respect to variables such as, different material compositions, thickness of coatings and linings, substrate preparation and different sample preparation methods.

4.2.6 Anticipated Products from the Proposed Program

The results of Phase I will help to establish a reliable in-house FGD materials evaluation capability, and a reference materials performance data base. In Phase II it is anticipated that possible new materials, with potential for application in FGD systems will be identified. The overall results will help Ontario Hydro to address the potential FGD materials failure problems in a reliable and well informed manner.

5.0 BUDGET ESTIMATE

The estimated total cost of the proposed two-phase twenty four month program is $165,000 and the breakdown of the cost is shown below:

Phase I	
Manpower 33 man/weeks	$ 70,000
M&E, External Services	20,000
Total Phase I	90,000
Phase II	
Manpower 25 man/weeks	50,000
M&E, External Services	25,000
Total Phase II	75,000
Grand Total	**$165,000**

6.0 PROGRAM PLAN AND SCHEDULE

A program plan and schedule is presented in figure 2.

7.0 CONCLUSIONS

From the information available on scrubber materials performance and reliability, it can be concluded that failure of construcion materials in FGD systems is one of the major issues. This materials failure problem has existed in the past and will no doubt remain an ongoing problem in the future. In view of

FIGURE 2

Plan of Work

TITLE: An R&D Program on Protective Coatings Used in FGD Systems

Major Tasks / Time/Months	Phase I						Phase II					
	2	4	6	8	10	12	2	4	6	8	10	12
Phase I (33 M/W)												
1. Review and selection of materials & service conditions of FGD Systems. (5 M/W)												
2. Design of experiments. (10 M/W)												
3. Testing of Materials. (10 M/W)												
4. Characterization and evaluation. (8 M/W).												
Phase II (25 M/W)												
1. Review of new materials. (3 M/W)												
2. Selection of Materials. (2 M/W)												
3. Preparation of Test Samples. (4 M/W)												
4. Testing of Materials. (10 M/W)												
5. Characterization and evaluation. (6 M/W)												
Manpower - Man/Weeks (M/W)	3	3	6	8	6	7	3	3	5	5	4	5

Ontario Hydro's commitment to controlling SO_2 emissions, it is imperative that an in-house R&D Program to address materials failure issues be in place.

In this document, the Materials Chemistry Section of the Chemical Research Department has formulated an R&D program on protective-coatings in FGD scrubbers. The overall objective of the program is to establish an effective in-house testing, evaluation, problem solving and research capability for FGD systems materials at Ontario Hydro. The proposed program has two twelve-month phases. In Phase I, in addition to the review of FGD system components, service environments and currently used materials; laboratory experiments will be designed to closely simulate scrubber environments and test various commercially available materials. The results of this phase will help to standardize experimental test methods and establish in-house materials testing capability, and a reference data base for various scrubber materials within Ontario Hydro. In Phase II of the program, various commercially available new materials will be reviewed for their potential applications in FGD systems; materials with most promise will be tested under similar experimental conditions developed in phase I. The results of phase II, in comparison with phase I results, will help to evaluate new materials for potential FGD applications.

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